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Coupling of Population and Settlement Change Trends in Traditional Rural Areas and Urban–Rural Development Spatial Patterns: A Case Study of Heilongjiang Province, China

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Abstract: Achieving the dual development of rural revitalization and urbanization is an important strategic goal of China's current modernization. Rural population and settlements are the main components of the countryside in traditional agricultural areas, and play an important role in the development of the countryside itself in terms of urban and rural land use and in the formation of urban and rural development patterns. This study analyzes the spatial and temporal changes in rural populations and settlements at the township level, as well as the degree and type of coupled development. A framework for urban–rural development relationships based on different types of coupled development is proposed, and a model of urban–rural forces is constructed to derive the spatial pattern of urban–rural development at the township level that may be formed in the future. Our study shows that the rural population and settlements in the study area are characterized by significant spatial and temporal dynamics, indicating that traditional rural areas are in a process of rapid development and change. The results of the township-level coupling measurements present four types of development in terms of the spatial pattern of urban–rural development: A-type is most likely to produce new cities or satellite towns in the Jixi–Harbin–Qiqihar area in the future; B-type is the fastest dying area in the future, located in the Harbin and Qitaihe clusters, with a tendency to merge into Harbin; C-type is the area to be focused on in the future to attract population and strictly control the growth of the rural settlement area to avoid it turning into B-type; D-type may develop regional township centers in the future in the combined area of Jiamusi City, Suihua City and Mudanjiang City. The results of the study provide experience in realizing rural revitalization according to local conditions. The new spatial pattern of urban–rural development provides an important reference for formulating land use policies, optimizing urban–rural land allocation and realizing integrated urban–rural development strategies.

Keywords: population and settlement; coupling model; urban–rural development patterns; traditional rural

1. Introduction

Under the dual demands of urbanization and rural revitalization, the relationship between urban and rural areas has undergone drastic and complex changes. On the one hand, rapid urbanization has brought certain impacts to the countryside, causing a part of the countryside to decline rapidly [1,2]. On the other hand, the expanding cities, through the radiation effect, have brought development opportunities to the countryside, causing some villages to develop rapidly [3,4]. The former attempts to improve its own state through the revitalization and restructuring of

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the countryside, while the latter hopes to improve its urbanization and economic development capacity by further attracting population, industrial development and adjusting land use structure. This process has produced different trends of change under the coupling of multiple factors in urban and rural areas, which in turn has resulted in different types of urban–rural development relationships [5]. This is a process of change that has been experienced by all developed and developing countries around the world; however, for China, which is now in a rapid development stage, this process of change is rapid and significant, and there is an urgent need to establish a pattern of urban–rural spatial development that can promote the integration of urban and rural development.

Since China's reform and opening up in 1978, the relationship between urban and rural areas has undergone rapid changes. In general, it has moved from the stage of "urban–rural dual structure" to the stage of "integrated urban–rural development" [6]. At the stage of urban–rural dual structure, it is typical that there is a significant gap between the underdeveloped countryside and the rapid modernization and development of the city, which hinders the overall socio–economic development [7]. In order to solve this problem, the 18th National Congress of the Communist Party of China (CPC) put forward the strategic goal of integrated urban–rural development. For the countryside, on the one hand, it is necessary to convert farmers into urban residents through urbanization; on the other hand, it is necessary to improve the production, life and lifestyle of the countryside through urban–rural integration [8,9]. In this process, the mobility of the rural population increases, rural industries begin to diversify, and the demand for construction land by township enterprises becomes stronger [10]. China, as a country with a large population, has implemented a strict system of protecting arable land. The use of construction land for industrial production and other non–agricultural land use is restricted to settlements in the countryside. Therefore, the state and trend of rural development can be quickly understood by analyzing the characteristics and coupling effects on the development of population and settlement use [11]. At the same time, the city is attractive to rural residents because it can provide better employment, living standards and ecological environment. This attraction further promotes the movement of the rural population. Moreover, with the city as an administrative center, the government, through the formulation of land planning and use policies, achieves control of new settlements in the countryside. These roles, combined with trends in the development of rural human settlements, form the basis for changes in urban–rural development relations, and may lead to the formation of a new spatial pattern of urban–rural development. The essence of this pattern is the transformational development of urban and rural land use.

Currently, the revitalization and development of the countryside is an important strategic goal of the country, and the Communist Party of China (CPC), in the report of the Twentieth National Congress, proposed to address this issue by "insisting on giving priority to the development of agriculture and rural areas, insisting on the integrated development of urban and rural areas, and unimpeded flow of factors between urban and rural areas". The aim is to achieve integrated urban–rural development through rural revitalization. This is not only a key concern for national development, but also a topic of general interest in the current academic community [12–14], and is of great significance in guiding other developing countries to achieve modernization. In the existing studies, the research around the state and trends in rural development is divided into different directions of concern. Some scholars have studied from the perspective of rural decline, focusing on population loss [15,16] and rural hollowing out [17,18]. Some scholars have conducted research from the perspective of rural value enhancement, focusing on rural urbanization [19,20] and rural settlement consolidation [21,22]. In addition, some studies have taken the state and trends of rural development as the basis to study the pattern of urban–rural development [23–25], and have been divided into two research focuses. One research focus is to drive integrated urban–rural development with rural revitalization. For example, some scholars propose to achieve urban–rural integration by improving the service capacity of central villages to surrounding villages [26]. Another research focus is to construct an urban–rural development pattern from the perspective of urban–rural interaction. For example, some scholars have conducted a comprehensive assessment of China's urban–rural development transformation based on the three aspects of urban–rural development–structure–coordination [27]. At the same time, thanks to the development of remote sensing technology and geographic information system (GIS) technology, the above studies and others have used these two methods to conduct spatial and quantitative research [28], so that the relationship between urban and rural development can be visualized spatially and become more spatially accurate, providing guidance for the adjustment of land planning policies.

A synthesis of existing research has found that understanding the development status and trends of villages is the basis for optimizing the future pattern of urban and rural development, but different types of villages will develop in very different directions and therefore play completely different roles in the future pattern of urban and rural development. There is a need for studies to quickly identify villages with different coupled development types and understand their development trends. Population is the main component of agricultural activities in traditional villages, and settlements represent the areas where industries are concentrated; the two become the main components of traditional villages. This study describes the development trend of different types of village based on dynamic changes in the coupling of the two, i.e., the development trend of different types of coupled villages [11,29,30]. It should be noted that this coupling is the role of the rural population and its rural construction land, and does not show whether it is coordinated development. Precisely because this study considers both coordinated and uncoordinated types of coupled development, it can provide a more comprehensive picture of the future development trends of different types of villages. Since the urban–rural development pattern that forms in the future has a certain degree of predictability, this study is more conducive to understanding the future development trends of village population and settlement dynamics than static studies. At the same time, on this basis, the attraction of large cities to villages is taken into account to analyze the possible future pattern of urban–rural development in a region.

Heilongjiang Province is an important grain production base in China, with a total grain output of 155,764 million catty in 2023, accounting for 11.2% of the country's output and ranking first in the nation [31]. The region has an important role in ensuring national food security. Therefore, for a long time, villages in the region have taken planting as the leading industry, which is in line with the characteristics of traditional villages. In recent years, with modernization, both the population and settlements in the region's villages have undergone significant changes and presented different types of development. The urban–rural development pattern of different types of villages in the future will be of great value in realizing the revitalized development of villages in the region, and building a benign urban–rural interaction mechanism.

This study thus takes Heilongjiang Province as the study area, with townships with rural population concentration as rural spatial units, and built–up areas with urban population concentration as urban spatial units. It describes the spatial and temporal change patterns of population and settlements in 1,465 townships from 2016 to 2021, determines the type of coupled development in each township, and constructs a new framework for modeling the relationship between urban and rural development. Under this framework, an evaluation system is constructed from the three directions of "employment environment attraction, living environment attraction and ecological environment attraction" to comprehensively evaluate the attractiveness of 12 prefecture–level cities in the study area. The concept of urban–rural development force and the quantitative measurement model are proposed, and the new urban–rural development pattern is visualized based on the results of the measurement combined with GIS software.

2. Materials and Methods

2.1. Study Area

Heilongjiang Province is located in northeastern China (between E121°11′–135°05′ and N43°26′–53°33′), bordering Russia to the north and east, China's Inner Mongolia Province to the west, and Jilin Province to the south. The study area includes 12 prefecture–level cities and the Daxing'anling district, under which are 1,465 townships where the rural population is concentrated. Each prefecture–level city has a built–up area where the urban population is concentrated. The study area is part of the Daxing'anling Mountains in the west, with the northwest–southeast–trending

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Xiaoxing'anling Mountains connected to it, and the Zhangguancai Mountains in the east. To the south of the Xiaoxing'anling Range is the Songnen Plain, and to the northeast of the Zhangguancai Ridge is the Sanjiang Plain, with most of the towns and villages located in these two major plains areas. Heilongjiang Province is an important food–producing region in China with vast rural areas. The townships in this study account for 98.07 per cent of the total area of the study area. Due to their location in the borderland, the cities within them are more closely related to the neighboring townships (Figure 1).

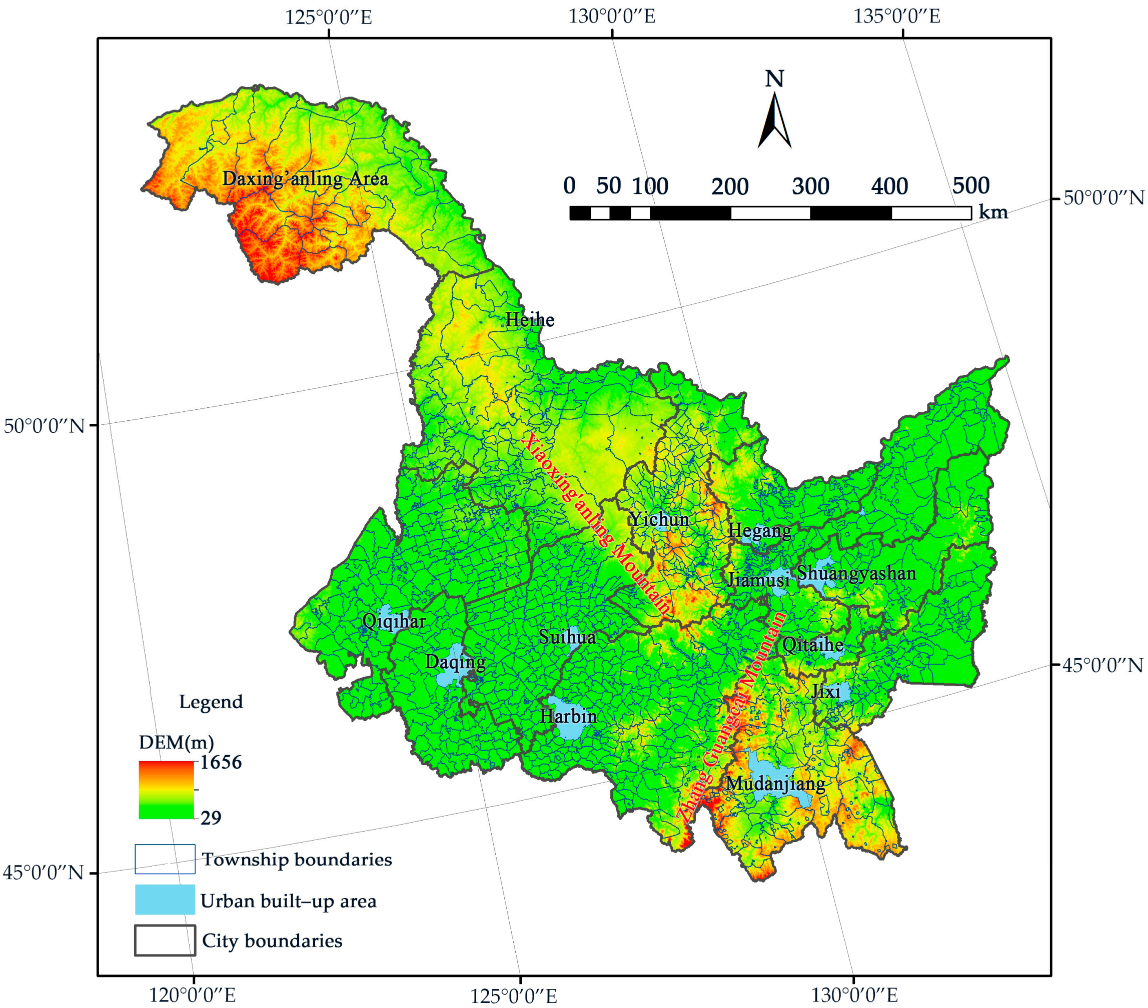

Figure 1. Overview of the study area.

2.2. Data Sources and Preprocessing

The data used in this study include the spatial distribution of the population data, rural settlement data, urban built–up area data, administrative division data and the urban attractiveness dataset. The spatial distribution of the population data (LandScan) was developed by the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) and provided by East View Cartographic (https://www.eastview.com/) at a spatial resolution of 1 km, and includes data for both 2016 and 2021. It is one of the best datasets available for global vital statistics analyses, using an innovative approach that combines geographic information system (GIS) and remote sensing (RS) imagery. In contrast, the national census data conducted in China is not dynamic and is based on household registration surveys; therefore, the results of these two data sources are very different, and LandScan data are used in this research. The rural settlement data were obtained by interpreting Landsat remote sensing images (https://www.gscloud.cn/sources/index?pid=263) with a spatial resolution of 30 m, including two periods of data in 2016 and 2021. The population change data (2016–

2021) and rural settlement use change data (2016–2021) were obtained. The outlines of municipal administrative districts in Heilongjiang Province and the outline of Heilongjiang Province were obtained from the Resource and Environment Science and Data Center of the Chinese Academy of Sciences (https://www.resdc.cn/Datalist1.aspx?FieldTyepID=20,0). The spatial extent of townships in Heilongjiang Province was obtained from the Geographic Remote Sensing Ecological Network Platform (http://www.gisrs.cn/). The data on urban built–up areas refer to the administrative area of the main urban area of the city, which comes from the Ministry of Civil Affairs of the People's Republic of China (http://xzqh.mca.gov.cn/map), and was overlaid with the township data of Heilongjiang Province to obtain the urban built–up area data. The comprehensive urban attractiveness dataset consists of three parts—employment environment, living environment, and ecosystems—including 19 indicators (Table 1), and the data were all obtained from the "Heilongjiang Statistical Yearbook 2022 "(https://kns.cnki.net/kns8s/search?classid=HHCPM1F8&kw).

Table 1. Evaluation table of the overall attractiveness of the city.

Target Level	Normative Layer	Indicator Layer	Unit (of Measure)
Employment environment	Economic level	Gross regional product	CNY Millions/ 100 persons
		Economically dense	CNY Millions / 100 hectares
	Employment level	Unemployment rate in urban area	%
		Number employed in urban non-private units	Person
	Pay level	Average wage of employed persons in Urban Non-Private Units	RMB/CNY
		Average wage of employed persons in urban private units	RMB/CNY
Environment	Consumption level	Urban annual per capita disposable income of urban households	RMB/CNY
	Housing level	Total assets of real estate	CNY Ten thousands
		Total sale of commercialized buildings	CNY Ten thousands
	Public transport	Total road area per capita	m/person
		Number of public vehicles under operation	Unit
		Length under operation	Km
	Public service facilities	Enrollment of compulsory education	%
		Number of institutions and public cultural facilities	Unit
		Number of hospitals	Unit
Ecological environment	Ecological status	Area of parks and green land	Km^2
		Water resources per capita	Million m^3 / 100 persons
		Emissions volume of air contaminants (sulfur dioxide, nitrogen oxide, smoke and dust)	Ton
		Volume of waste water discharged	Ten thousand tons

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2.3. Methodology

2.3.1. Patterns of Spatial and Temporal Changes in Population Size and Settlement Use in Rural Areas

In this study, the raster data of the spatial distribution of population in 2016 and 2021 were converted into point datasets P_{t1} and P_{t2}, respectively. The pattern of population change in the rural area P_{ij} was derived from the difference in population number (i.e., using P_{t2} –P_{t1}) in each of the same spatial locations in two different periods. The sum (Δo_{i1}) of the differences in population size (P_{t2}–P_{t1}) within each township in the study area was counted separately to obtain the population change in terms of townships. The same method was used to obtain the total change (Δo_{i2}) in township–scale rural settlement area in the study area from 2016 to 2021.

Further analysis of the spatio–temporal separate pattern was based on Anselin Local Moran's I model [32].

The Local Moran's I statistic of spatial association is given as follows:

$$I_i = \frac{x_i - \overline{X}}{S_i^2} \sum_{j=1, j\neq i}^{n} w_{i,j}(x_j - \overline{X}) \tag{1}$$

where xi is an attribute for feature i, $\overline{X}$ is the mean of the corresponding attribute, and $w_{i,j}$ is the spatial weight between feature i and j :

$$S_i^2 = \frac{\sum_{j=1, j\neq i}^{n} (x_j - \overline{X})^2}{n-1} \tag{2}$$

where n equates to the total number of features.

The score for the statistics is computed as follows:

$$z_{I_i} = \frac{I_i - \mathrm{E}[I_i]}{\sqrt{\mathrm{V}[I_i]}} \tag{3}$$

$$\mathrm{E}[I_i] = -\frac{\sum_{j=1, j\neq i}^{n} w_{ij}}{n-1} \tag{4}$$

$$\mathrm{V}[I_i] = \mathrm{E}[I_i^2] - \mathrm{E}[I_i]^2 \tag{5}$$

2.3.2. Coupling of Population Mobility and Settlement Use in Rural Areas Degree Models

The countryside's population changes constantly over time, and the use of its settlements is constantly being planned and adjusted. The creation and implementation of new land use plans are often slower than the rate of change in population movements, and therefore may show inconsistencies at certain times, such as the loss of rural population against a growth trend in settlement use, which can further reduce the efficiency of the use of settlements for the rural population.

There are several types of coupling relationships in a given time period, depending on the trends in population and settlements use in the countryside: A–type is a simultaneous increase in rural population and settlement area; B–type is a simultaneous decrease in both rural population and settlement area; C–type is a decrease in rural population and an increase in settlement area; and D–type is an increase in rural population and a decrease in settlement area. The other types (O–type) include several situations: a. No change in the population and settlement area has taken place in the middle of the population, thus there is an inability to measure the coupling of change processes; therefore, it is excluded from the scope of the study. b. Population changes, and the settlement area

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remains unchanged. c. Population remains unchanged while the settlement area changes. Since this study investigated the change trends in rural population and its settlement use and their coupling, cases b and c do not meet the requirements of the study and are not discussed (Figure 2).

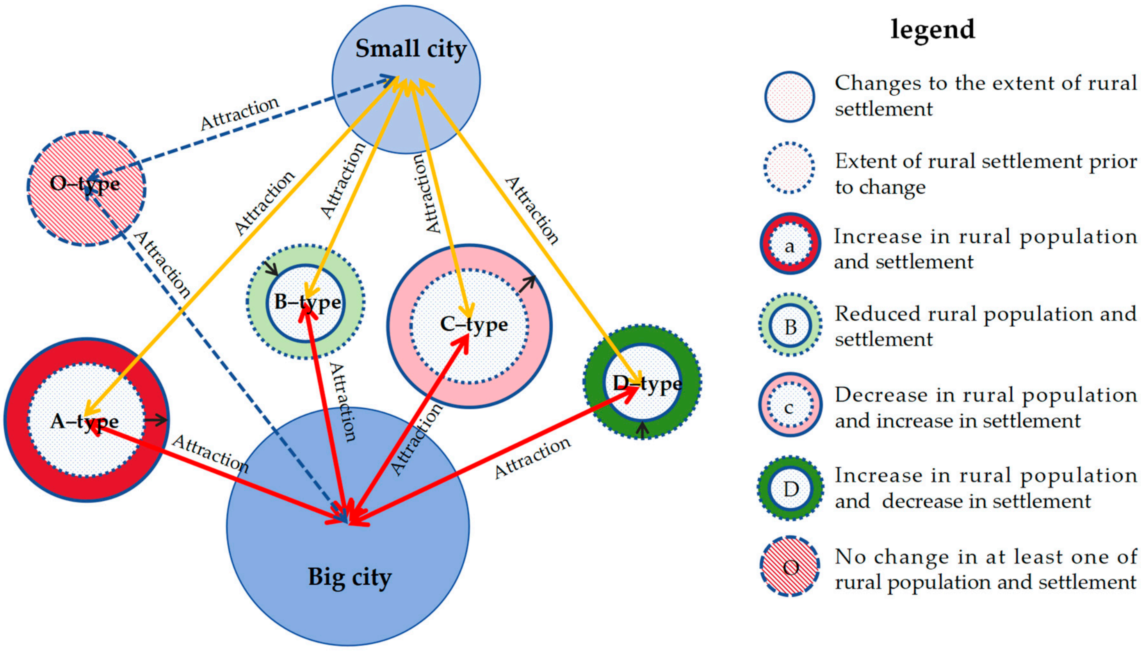

Figure 2. Types of coupled relationship between population and settlement changes in the countryside.

If rural settlements are considered as a whole, the opposite of these are urban settlements. Each rural agglomeration is attracted to other urban agglomerations of different sizes and spatial locations, further generating the following coupling development types (TCD): A–type villages are likely to develop further into small towns in the future due to the simultaneous increase in both population and settlement area, indicating that they have an advantage in terms of demographic attractiveness and land–use plans, and belonging to the “agglomeration enhancement type “. B–type villages, due to their simultaneous decrease in both population and settlement area, indicate that their demographic attractiveness is declining and their settlement use plans are in a state of austerity, and therefore may gradually shrink or even disappear in the future, belonging to the ”gradual extinction type “. C–type villages, whose populations are decreasing, have advantageous settlement schemes, so the efficiency of rural settlement use is low. These areas currently need to take the most measures to adjust and have the greatest potential to accommodate the population; thus, they should adopt active population and land use policies. They belong to the “hollowness aggravated type”. D–type villages have a growing population, but their settlement use programs are in a contractionary state. The efficiency of settlement use in the countryside is increasing, and it is not easy for them to accommodate an increasing population in the short term; thus, it is most important for them to focus on the maintenance and improvement of the living environment. They belong to the “internal intensification type”.

In this study, the coupling degree model was used to analyze the interactive dependence of the two elements, namely, the degree of population change and the number of settlement changes in rural areas; the higher the degree of coupling, the more frequent the interaction between the two, and the higher the degree of their mutual influence and dependence. Under the coupling effect, the four types of TCD will have different impacts according to their coupling degree. Overall, with a higher degree of coupling, a change in one of the two factors will promote change in the other factor, which in turn produces an expansion effect, making the performance characteristics of the type more significant. With a rise in the degree of coupling in A–type villages, the rural area becomes more

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functionally capable of agglomeration and enhancement, and in the future, it may become a newly emerging small city or a satellite city of a large city. With a rise in the degree of coupling in B–type and C–type villages, the villages of the area die out more quickly, and may be annexed in the future. As the coupling degree rises in C–type villages, the utilization rate of the rural settlements in the area declines further, and the hollowing out characteristics become more significant, which requires more attention and governance in the future. As the coupling degree rises in D–type villages, the efficiency of the rural settlements in the area rises further, and the area is more likely to become the center of the regional township in the future.

We identified statistically significant hot spots and cold spots utilizing the hot spot analysis tool. We analyzed the spatial clustering characteristics of areas with high and low coupling values in the TCD. Then, we created standard deviational ellipses to summarize the spatial characteristics of H–VAE utilizing the standard deviational ellipse tool. Please refer to ArcGIS 10.8 software for details about these two tools.

The coupling degree model is calculated through the following steps:

(1) Indicators were standardized in this study using the extreme variance method.

The formula for the positive indicator is the following:

$$n_{ij} = \frac{\Delta o_{ij} - \min(\Delta o_{ij})}{\max(\Delta o_{ij}) - \min(\Delta o_{ij})} \tag{6}$$

The formula for the negative indicator is the following:

$$n_{ij} = \frac{\max(\Delta o_{ij}) - \Delta o_{ij}}{\max(\Delta o_{ij}) - \min(\Delta o_{ij})} \tag{7}$$

where delta o_{ij} is the amount of rural population change and rural settlements change from 2016 to 2021.

(2) Indicator weights: Since only the coupling of two factors, population and land change, is considered, and both are of equal importance, the weight was set at 0.5.

The 2016–2021 composite indicator of rural population change is as follows:

$$U_1 = 0.5 \times n_1 \tag{8}$$

The composite indicator of change in rural settlement use for 2016–2021 is as follows:

$$U_2 = 0.5 \times n_2 \tag{9}$$

(3) The relationship between the coupled effect of the amount of population change and the amount of settlement change in rural areas from 2016 to 2021 was calculated using the coupling degree (C_j), which is given by the following formula:

$$C_j = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2} \tag{10}$$

2.3.3. Modeling The Spatial Relationship between Urban and Rural Development

The interaction between the countryside and the city is manifested in the mutual attraction of urban and rural populations and the implementation of planning and utilization policies targeting rural settlement use indicators, including the adoption of loose or tight rural settlement use planning policies, which increase or decrease the amount of land available for building in the countryside, and land planning and utilization policies; these in turn use the agglomeration or dispersion of the population as an important reference. The closer a settlement is to the city spatially and the stronger the overall attractiveness of the city itself, the more likely the population is to be attracted (the main role). Based on the TCD analysis, the framework of the future urban–rural development relationship model is further explored under the role of urban attraction and the characteristics of coupled changes in rural population and settlements use (Figure 3).

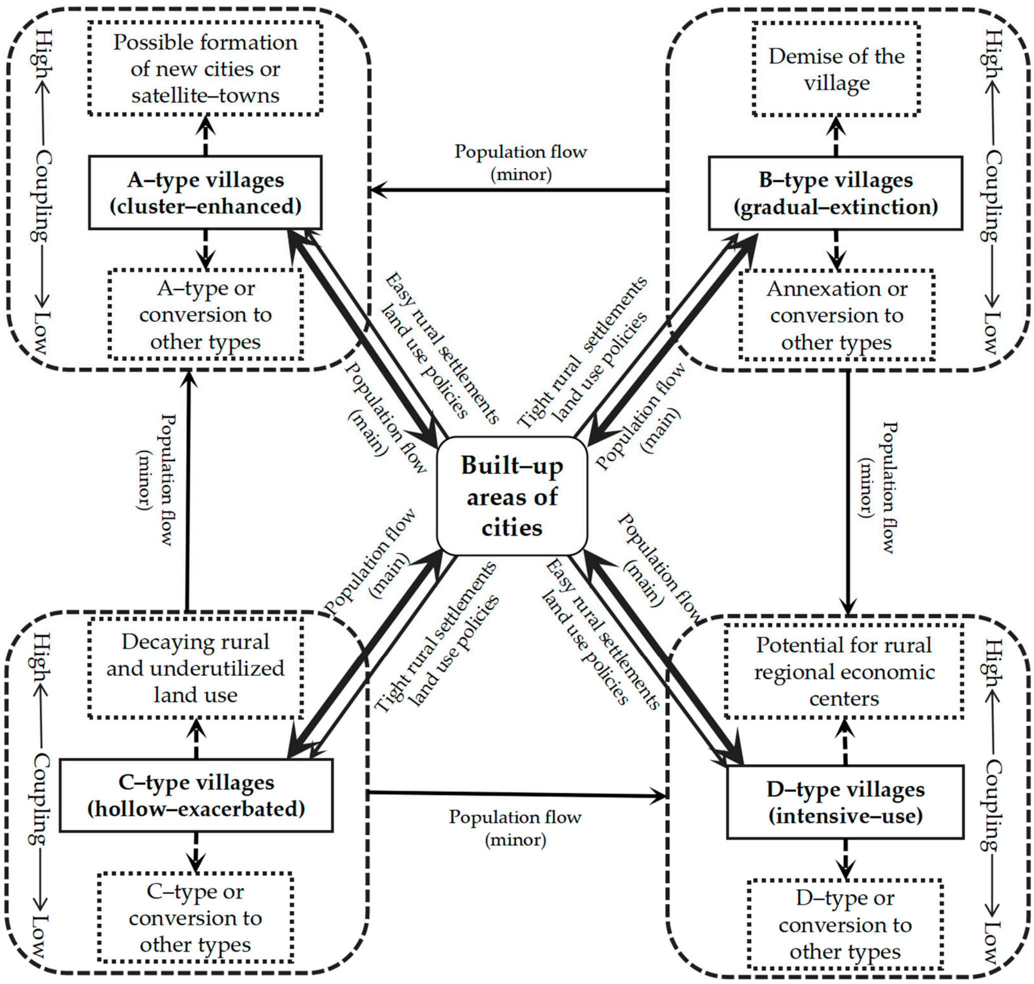

Figure 3. Model of urban–rural development relationship based on coupled characteristics of the rural population and settlements framework.

The comprehensive attractiveness of a city is a state shown by the city over a certain period of time. In this research, we selected 19 indicators Q_{ij} (Table 1) to evaluate the comprehensive attractiveness of each prefecture–level city in Heilongjiang Province in 2021. Combined with the characteristics of the coupled changes in rural population and residential use from 2016 to 2021, the attractiveness model of urban and rural development is constructed based on the gravity model [33].

The calculation steps and specific formulae are as follows:

(1) Calculating the combined attractiveness of cities (C_j)

a. Indicator assimilation and standardization: 19 indicators were assimilated and standardized in this study using Equation (1) and Equation (2).

b. Calculation of indicator weights w_j: In this study, the entropy value method [34] was used to calculate the indicator weights.

$$Q_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{11}$$

$$e_j = -k\sum_{i=1}^{m} Q_{ij} \ln Q_{ij} \tag{12}$$

$$k = \frac{1}{\ln m}, \text{ m is the number of prefecture–level cities} \tag{13}$$

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$$g_j = 1 - e_j \tag{14}$$

$$w_j = \frac{g_j}{\sum_{j=1}^{n} g_j}\text{, } n \text{ is the number of indicators} \tag{15}$$

c. Obtain the weighted normalization matrix Zij:

$$Z_{ij} = Q_{ij} \times w_j \tag{16}$$

d. Composite index for each evaluation object [35]:

$$C_i = \sum_{j=1}^{n} Z_{ij}\text{, i=1...m, j=1...n.} \tag{17}$$

(2) Rural–Urban Development Forces Model

Urban–rural development force (URD) is used to measure the size of the force to form a new pattern of urban–rural development under the coupling effect of urban attraction C_j and rural population and settlements C_i. In this research, we constructed the attraction model of URD based on the gravitational formula of Newtonian mechanics. r_{ij} is proportional to C_i and C_j, and inversely proportional to the spatial distance between urban and rural areas, d_{ij}.

$$URD = R_{ij} = \frac{C_i \times C_j}{d_{ij}^{\ 2}} \tag{18}$$

The attraction of urban–rural development exists in each township and each city, but the largest force (maxR_j) has the most important effect on the formation of the spatial pattern of future urban–rural development (Figure 4).

$$\max R_j = \frac{\max(C_i \times C_j)}{\min d_{ij}^2} \tag{19}$$

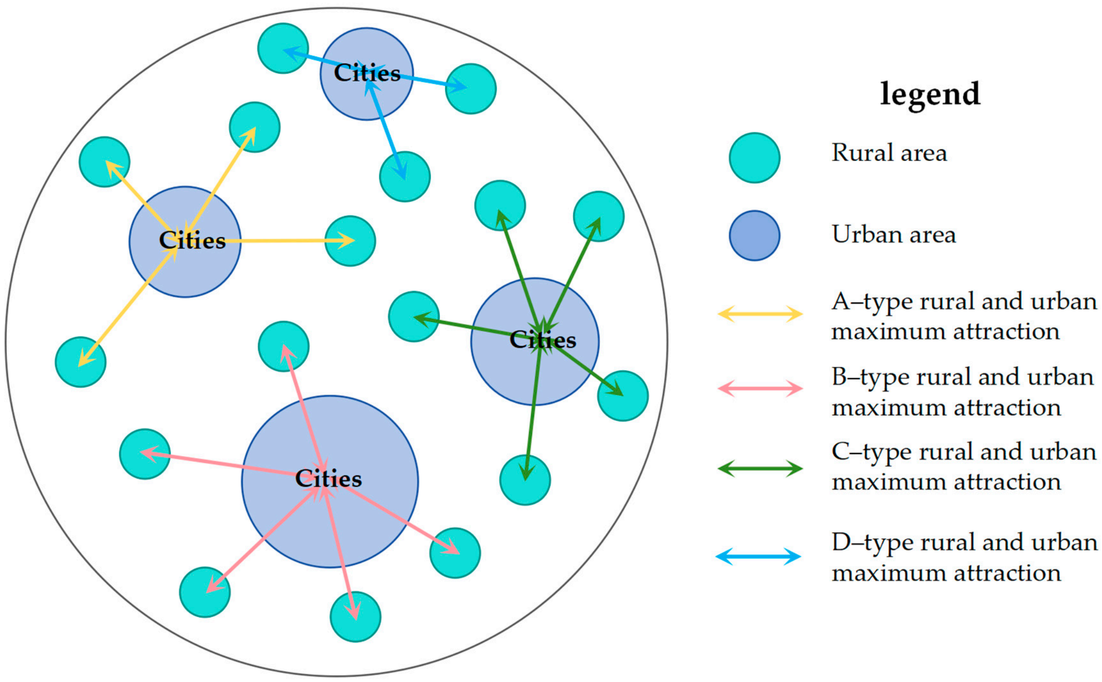


Figure 4. TCR spatial relationship model for urban–rural development.

3. Results

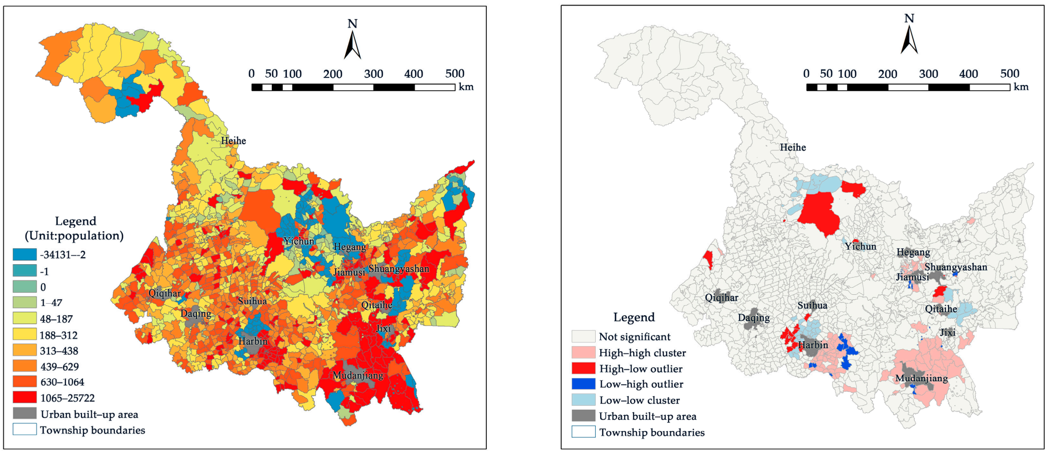
3.1. Patterns of Spatial and Temporal Changes in Population Size and Settlement Use in Rural Areas

3.1.1. Spatial and Temporal Patterns of Population Change in Rural Areas

In 2016–2021, 1137 out of 1465 townships in the study area underwent an increase in total population. This accounts for 77.61 per cent of the total number of townships, with a total increase of 88,0006 people. There were 153 townships in a state of decline, accounting for 13.46 per cent of the total number of townships, with a total decline of 291,192 people. The township with the largest increase in population had an increase of 25,722, and the township with the largest decrease in population had a decrease of 34,131.

In terms of spatial clustering characteristics, high–value zones were mainly distributed in the southeastern part of the study area, specifically in the southeastern part of Harbin City, as well as in the northwestern part of Mudanjiang City. Low–value areas are mainly distributed in the northern part of the study area, the northwestern part of Harbin City, as well as in Qitaihe and Shuangyashan. High–low outliers (high–value areas surrounded by low–value areas) are mainly distributed in the northwestern part of Yichun, in the Zhanhe Forestry Bureau and Xiangyang Township, as well as in the western part of Harbin City, in the areas of Haicheng Township, Jiangjia Township and Kangrong Township. Low–high outliers (high–value areas surrounded by high–value areas) are mainly distributed in the eastern part of Harbin City, in Sanbaosi Township. Low–value zones are mainly distributed in Sanbao Township and Capeshan Township in the eastern part of Harbin City. Overall, the areas showing agglomeration characteristics are mainly distributed in the areas of Xiaoxing'anling and Zhangguangcailing in a ring–like distribution (Figure 5).

Since the LandScan data are based on a combination of remote sensing imagery and demographic data to represent the state of changing population dynamics, this indicates that, during the period of 2016–2021, the population activities in the rural areas of the study area generally showed an increase, which has a large potential economic value for the population. The future development of rural settlements is particularly important as a concentrated area of population activity.



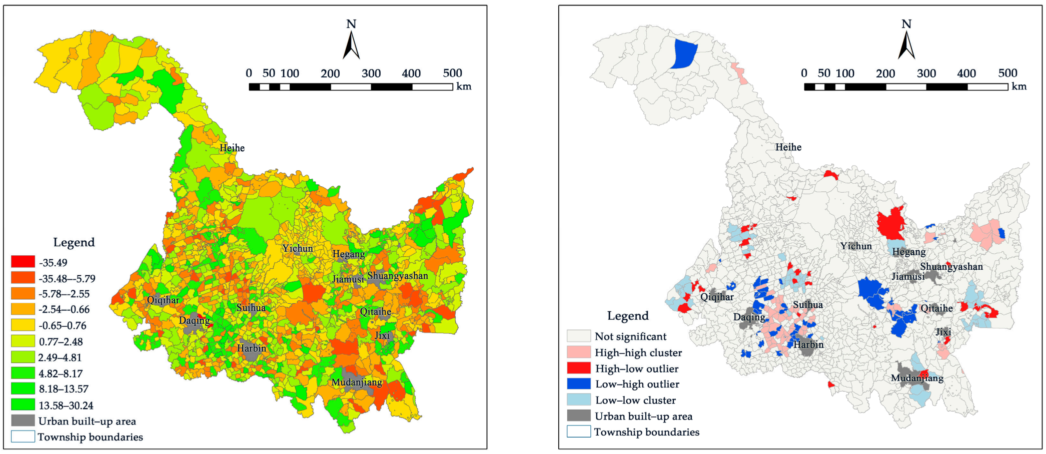
(a) (b)

Figure 5. (**a**) Rural population dynamics, 2016–2021; (**b**) cluster characteristics of rural population change, 2016–2021.

3.1.2. Spatial and Temporal Patterns of Settlements in Rural Areas

From 2016 to 2021, 848 out of 1465 townships in the study area showed an increase in settlement area, accounting for 57.88% of the total number of townships, with a total increase of 2285.23 km2. There were 533 townships in a state of decline, accounting for 36.38% of the total number of townships, with a total decline of 1039.57 km2. The largest increase in rural settlement area was 30.24 km2, and the largest decrease in area decreased by 35.49 km2.

In terms of spatial clustering characteristics, the high–value areas are mainly distributed in the southeastern and northwestern regions of the study area, specifically in the area surrounded by Harbin City, Daqing City, Suihua City and the northwestern part of Shuangyashan City. Low–value areas are scattered mainly in the western and northern parts of Qiqihar, northern Suihua, northern Hegang, eastern Qitaihe and around Mudanjiang. High–low outliers (high–value areas surrounded by low–value areas) are mainly in the northern part of Hegang. Low–high outliers (low–value areas surrounded by high–value areas) are mainly in the Daxing'anling region of Walagan Township and the forest areas of Xiaoxing'anling and Zhangguangcailing in the western part of Qitaihe City (Figure 6).



(a) (b)

Figure 6. (a) Change in rural settlements use, 2016–2021; (b) cluster characteristics of rural settlement changes, 2016–2021.

3.2. Characteristics of the Development of the Coupling of Population and Settlement Use in Rural Areas

According to the TCD results based on the spatial and temporal changes of rural population and settlements in the study area from 2016 to 2021, there are 658 townships of A–type, 47 townships of B–type, 100 townships of C–type and 447 townships of D–type. This indicates that "agglomeration and upgrading type" and "internal intensification type" are the main types of rural human settlement development in the study area, and are also the main types of future urban–rural development relationships.

The calculation of the coupling degree of different types showed that the coupling value of A–type villages is generally high, and the proportion of townships with a coupling degree greater than 0.8 is 72.95%, while the proportion of townships with a coupling degree lower than 0.2 is only 6.84%, indicating that this type of township has a stronger ability to develop in the future. The B–type coupling value had the highest proportion of all the types, and the proportion of townships with a coupling degree greater than 0.8 was 93.627%, which indicates that the future development trend of this type of township is rapid decline. C–type coupling values are more evenly distributed, with 16% of townships larger than 0.8, 26% of townships in [0.8,0.6), 28% of townships in [0.6,0.4) and 23% of townships smaller than 0.2. This indicates that C–type townships are less likely to intensify hollowing out in the future and more likely to shift to other types. The D–type coupling value is generally low, with 84.12% of townships having a coupling degree of less than 0.4 and only 2.01% of townships having a coupling degree of more than 0.8. This indicates that it is more difficult for D–type townships to continue to increase the intensity of settlement use in the future (Figure 7).

The A–type and D–type couplings are characterized by significant spatial agglomeration, with low values in the north and high values in the south. The highest value for A–type is concentrated in the area surrounded by "Harbin–Suihua–Mudanjiang", which is the area that is most likely to produce new cities or satellite cities in the future. The standard deviation ellipse shows a "northwest–

southeast" distribution, which is the development axis of emerging cities. According to the standard deviation ellipse, the highest value of D–type is concentrated in the area surrounded by "Harbin–Mudanjiang–Jixi–Qitaihe", and has a "northeast–southwest" distribution. It is the development belt of the core of the township area (Figure 8).

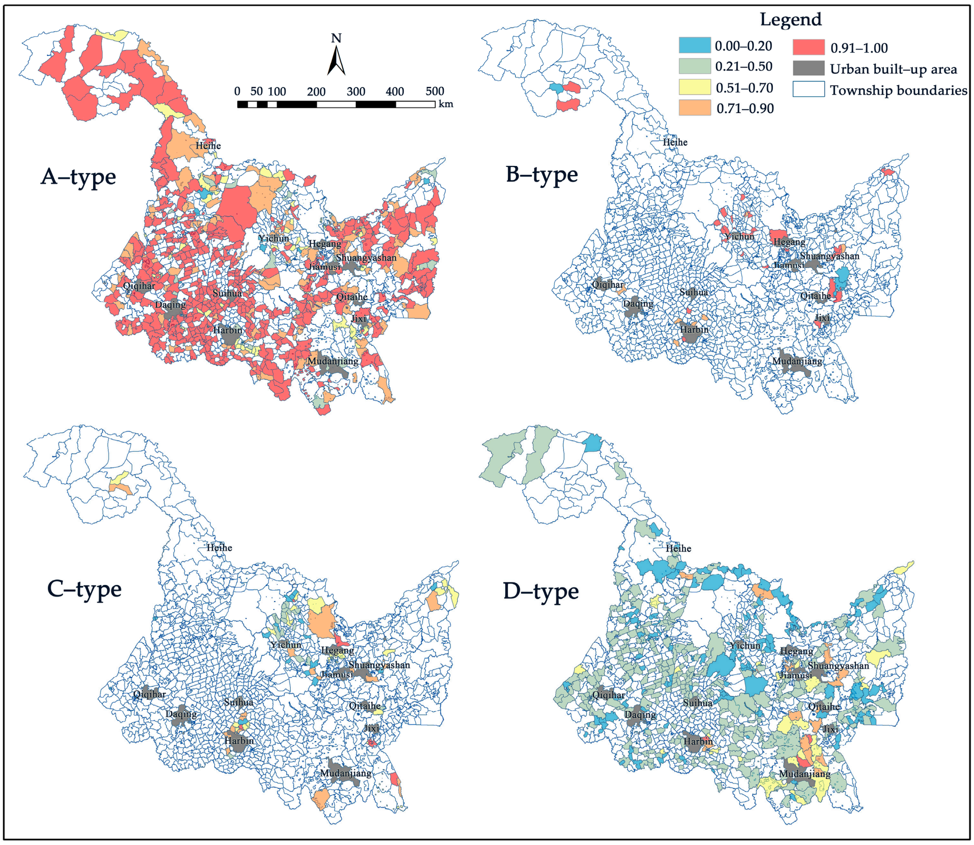
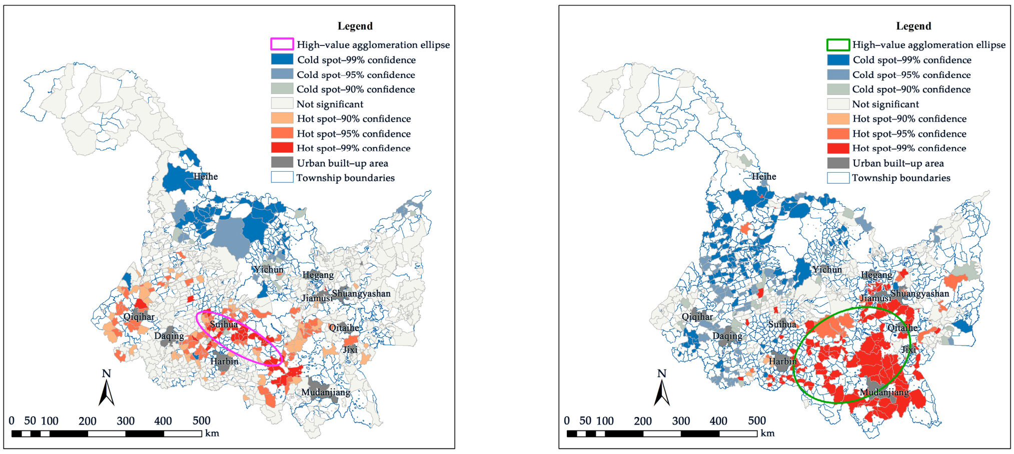


Figure 7. Characteristics of spatial distributions of TCD coupling degrees.



(a) (b)

Figure 8. (a) A–type agglomeration characteristics; (b) D–type agglomeration characteristics.

3.3. The Spatial Patterns of Urban–Rural Development

3.3.1. Calculation of the Comprehensive Urban Attractiveness of the Study Area

The results of the calculation of the comprehensive attractiveness of the 12 prefecture–level cities in the study area show that Harbin is the most attractive city, with a value of 0.7498. The second most

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attractive city is Daqing, with an attractiveness value of 0.5812. The third most attractive city is Mudanjiang, with an attractiveness value of 0.3204; this is similar to Qiqihar, which had an attractiveness value of 0.3050. The least attractive city is Yichun, with a value of only 0.1726. The rest of the cities have relatively similar combined attractiveness values, ranging from 0.21 to 0.26 (Table 2).

Table 2. Combined urban attractiveness values for the study area.

City Name	Harbin	Qiqihar	Jixi	Hegang	Shuangyashan	Daqing
Total Value	0.7498	0.3050	0.2431	0.2326	0.2260	0.5812
City Name	Yichun	Jiamusi	Qitaihe	Mudanjiang	Heihe	Suihua
Total Value	0.1726	0.2646	0.2493	0.3204	0.2440	0.2128

3.3.2. Calculation of Rural–Urban Development Forces in the Study Area

When calculating the urban–rural development forces (R_{ij}) for each township and prefecture–level city, the TCD results in a number of intricate relationships that are the product of the number of townships and the 12 cities. However, each township has a maximum urban–rural development force that points to the one city that is most attractive to it. Under this force, bundles of radial clusters are formed that are centered on a particular city (Figure 9).

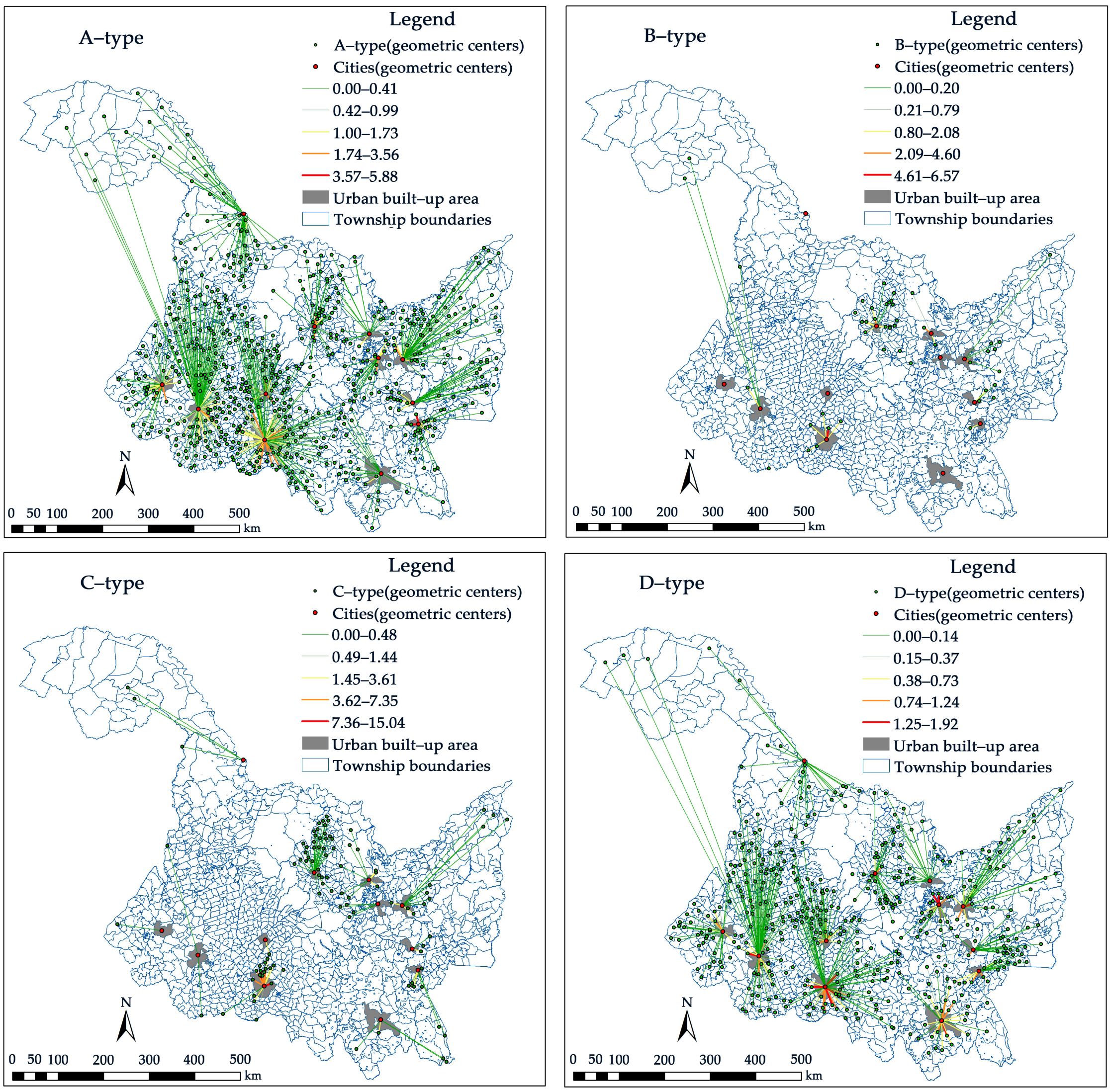

Figure 9. TCD urban and rural maximum attractiveness results.

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According to the average value of the maximum attractiveness of the 12 prefecture–level cities and townships of different types, it can be concluded that in terms of A–type attractiveness, the city of Jixi is ranked first, at 1.16; this is followed by Harbin and Qiqihar, at 0.77 and 0.71, respectively. In terms of B–type attractiveness, the city of Harbin is ranked first, with 2.27; this is similar to the city of Qitaihe, with 2.17. For C–type attractiveness, ranked first is the city of Harbin, and its attractiveness is the highest value of all of the types at 4.32. D–type attractiveness is more similar and at a lower level, with the values being below 1. Jiamusi has an attractiveness of 0.54, Mudanjiang 0.43 and Suihua 0.31 (Figure 10).

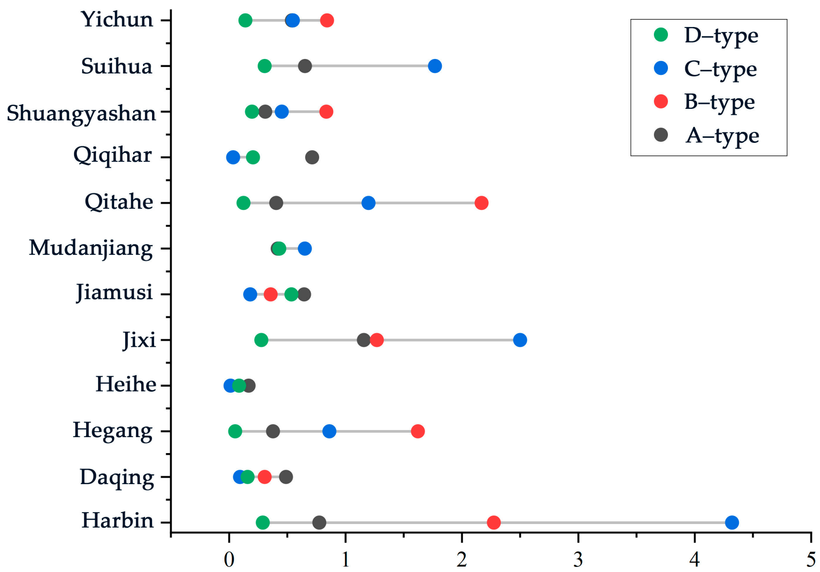

Figure 10. Average of the maximum attractiveness of the 12 prefectural cities and towns in the different categories.

3.3.3. New Spatial Patterns of Urban–Rural Development Under the Urban–Rural Development Dynamic

The A–type presents a spatial development pattern of urban and rural areas with "one center, two parts". The "one center" is located in the Harbin and Suihua areas, and combined with the calculated hotspots of A–type coupling values, there are 29 pairs of urban–rural spatial development relationships in its core ellipse (Table 3). The "one center" is located in the Harbin and Suihua areas, and combined with the calculated hotspots of A–type coupling values, there are 29 pairs of urban–rural spatial development relationships in its core ellipse (Table 3). The Qiqihar cluster in the west of the "two parts" includes 40 pairs of urban–rural spatial development relationships, and the Jixi cluster in the east includes 19 pairs of urban–rural spatial development relationships. The Jixi–Harbin–Qiqihar cluster as a whole shows an east–west development axis in space. When combined with the results of the calculation of the maximum urban–rural attractiveness value, this shows that the townships most likely to become emerging small cities or satellite towns in the future are Changgang Township and Manjing Township. These areas should be prioritized for land use planning and provided with liberal land use policies (Figure 11).

The urban–rural spatial development D–type pattern is characterized by a "triangular" distribution with the three cities of Jiamusi, Suihua and Mudanjiang as the apex. The Jiamusi group includes 17 pairs of urban–rural spatial development relationships, the Suihua group includes 36 pairs of urban–rural spatial development relationships and the Mudanjiang group includes 28 pairs of urban–rural spatial development relationships. Combined with the calculated D–type coupling value hotspots, there are a total of 20 pairs of urban–rural spatial development relationships within its core ellipse. Among them, the township that is most likely to become the center of the Mudanjiang region is Zhujia Township, and the center township of the Jiamusi region is Tulipa Township. Among

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them, the township that is most likely to become the center of the Mudanjiang region is Zhujia Township, and the central township in the future of the Jiamusi region is Tulongshan Township. Priority should be given to the increase in its settlement area in land planning and utilization policies (Figure 11).

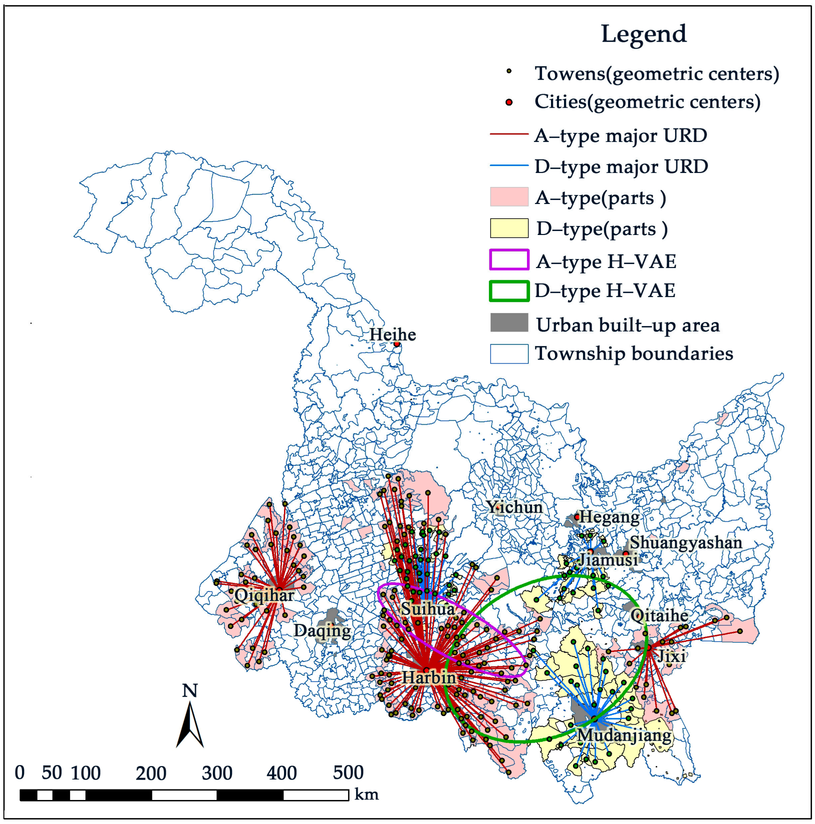

Figure 11. A – Type and D – Type patterns of major urban–rural development.

The nine B–type villages that will disappear the fastest in the future are located in the Harbin and Qitaihe clusters. Jiehe Township has the highest value of 6.5657 with the Qitaihe rural–urban development (RUD) forces, suggesting that it is likely to be annexed by the city of Qitaihe. Waibu Street has a value of 6.2688 with the Harbin rural–urban development forces, suggesting that the township is likely to be annexed by the city of Harbin. The remaining seven townships have relatively low values of developmental force with the city, and therefore, in addition to annexation by the city, they may also be annexed by other types of townships in the neighborhoods. Among them, A–type townships around Harbin City also have a strong attraction (Table 3).

C–type areas will need to be prioritized for treatment in the future. The management strategy is to strictly control the increase in rural settlement area, while attracting population increase, otherwise it may be converted to B–type. The areas with the greatest force of the 19 urban and rural pairs are all in the Harbin cluster, where the value of the force of road and street construction and Harbin's urban and rural development is 7.5187, which indicates that the possibility of interaction flow between Harbin and its population is greater, and it can provide more residential space for the population of Harbin City. The indicator of controlling the growth of settlements in the township can be used to subsidize the growth of urban construction land in Harbin to achieve a virtuous circle. The remaining townships could follow this practice or exchange population and land use indicators with other neighboring townships (Table 3).

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Table 3. Urban–rural development relationships forces of categories B and C.

B–Type Township Name	B–Type City Name	B–RUD	C–Type Township Name	C–Type City Name	C–RUD
855 Farm	Qitaihe	0.7891	Eight Town	Harbin	0.3546
Beixing Farm	Qitaihe	1.3187	Erba Town	Harbin	0.8999
Hongwei Town	Qitaihe	0.0000	Just Street	Harbin	0.8330
Yulin Town	Harbin	1.5273	Hulan Nongken	Harbin	0.4142
Daiyun Town	Harbin	1.3718	Kangjin Street	Harbin	0.3168
Jiehe Township	Qitaihe	6.5657	Lanhe Street	Harbin	5.5750
Yanglin Township	Harbin	1.0768	Shiren Town	Harbin	0.9549
Waibu Street	Harbin	6.2688	Yanjiagang Farm	Harbin	0.3152
Yongsheng Township	Harbin	1.1267	Changchunling Town	Harbin	0.1283
			Pair of Qingshan Town	Harbin	2.8515
			Fangtai Township	Harbin	1.3862
			Hulan street	Harbin	1.8028
			Construction Road Street	Harbin	7.5187
			Mengjia Town	Harbin	2.1639
			Youth farm	Harbin	5.6085
			Shenjia Town	Harbin	2.6981
			Shuangjing Street	Harbin	3.3648
			Xu Bu Township	Harbin	1.1773
			Changling Township	Harbin	2.6751

4. Discussion

4.1. The Coupling of Rural Population and Settlement Use Reflects the Dynamic Development Trend of the Countryside

The coupling of population and settlement use obtained in this study is the degree of interaction in dynamic change. How can this dynamic process be understood? In addition to the traditional living and residential functions, rural settlements also take into account the processing industry, service industry and other functional land. Therefore, the increase in its size reflects the level of development of that village. And with the development of urbanization, the population inevitably moves to the city, which involves both the process of re–organization of functional land use of rural settlements [36] and the process of coupling.

The system coupling theory [11,29,30] has been applied to a variety of disciplines such as social sciences, economics and geomatics, and some scholars have also used this theory to study the coupling synergy of "population–land–industry" [37]. Although this study only analyzes the coupling of population and settlements for the countryside, population is the main component of agricultural activities, while settlements is the area where other industries are concentrated. Therefore, the element of "industry" is implicit in the rural population and settlements, which simplifies the results of the coupling classification. In subsequent research, this implied factor can be analyzed as an explicit influence factor to obtain a richer type of rural coupled development.

Currently, China attaches equal importance to achieving urbanization and rural revitalization and development; therefore, as a hot research issue, the four different types of coupling proposed in this study have been addressed by scholars in different studies [11,29,30,36]. In this research, the four types were studied simultaneously and used to reflect the development levels and dynamic development trends of different villages. Combining them with the role of urban attractiveness provides a direction for the future agglomeration of various types of functional land in different types of village, and also reflects the direction of future rural revitalization.

4.2. The New Spatial Pattern of Urban–Rural Development Favors Integrated Urban–Rural Development

The urban–rural development relationship model with coupled characteristics of rural population and settlement use proposed in this study is easy to combine with empirical cases to obtain the new urban–rural development pattern that may be formed in the future by villages with different development types in the region under the interaction with urban attractiveness. The results have a clear spatial orientation and are of guiding significance for the rational allocation of land resources and the improvement of land use efficiency in the future.

The new spatial pattern of urban and rural development is the result of a combination of many elements, which, in addition to the types of elements already included in the calculations in the text, are also influenced by the topography and distribution of natural resources. This is determined by the basic natural conditions for the formation of rural settlements or cities and, therefore, is a potentially fixed influence. We found that 86.67% of the A–type townships are located at 100m–400m above sea level, and 85.19% of the D–type townships are located at 200m–500m above sea level, which indicates that these townships and cities are concentrated in areas with flat terrain. Therefore, the townships that will develop into small cities or satellite cities from the A–type townships are located in flat areas, as are the D–type townships that will form the centers. This is conducive to the reduction in transport costs, which in turn is conducive to the two–way free flow of urban and rural factors of production and the rational allocation of public resources, and promotes the integrated development of urban and rural areas. At the same time, declining B–type townships can achieve the reorganization of their population and land resources, which will become a backup resource for promoting urban–rural integrated development. C–type townships can focus on the management of the hollowing out problem, and their residential space can be a potential target for the clustering of functional land use.

According to the theory of echo and diffusion effects, there will be a cyclic accumulation between urban and rural areas affected by these two effects. The echo effect will widen the urban–rural gap, and the diffusion effect will narrow it [38,39]. The new urban–rural development pattern proposed in this study promotes integrated urban–rural development by spatially adjusting different types of urban–rural relationships, enhancing the diffusion effect of rural areas with development advantages (A–type and D–type) and reducing the echo effect of rural areas with development disadvantages (B–type and C–type). The realization of integrated urban–rural development is an important goal for China at this stage, and also an important direction for future scientific research.

4.3. Land–Use Policies Should Be Adjusted in Line with Urban–Rural Development Patterns

A new pattern of urban and rural development can only be realized if it is accompanied by a land policy. China places great emphasis on land planning and utilization, with “building a new township system” being one of the key elements of the latest round of Heilongjiang Provincial Land Planning (2021–2035). However, the current planning is centered around towns, and the policy on how townships can become new towns is not yet well developed. The development of category A townships in this study needs to be supplemented by corresponding land planning policies, including giving priority to land planning and development, optimizing its industrial layout with the city clusters it belongs to, and giving priority to the complementary functions and coordinated development of the paired cities that have the greatest urban–rural attractiveness. At the same time, the D–type townships obtained in this study can play the role of cities to a certain extent, and should also be optimized in terms of land planning policies, especially their insufficient settlements, which need to be prioritized and adjusted in line with the new industrial development plan.

Heilongjiang Province is located in a remote region of China, and most of its villages are still at the primary stage of agricultural–based economic development relative to the developed coastal regions of China. These villages play an important role in maintaining the country’s food security, and the strictest policies for the protection of arable land are being implemented. Priority is given to increasing rural settlement use, while at the same time ensuring that high–quality farmland is not damaged and that the total area of arable land is not reduced. Therefore, the B–type township settlements can be reasonably reduced to supplement the area of arable land occupied by other types

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of township. On the other hand, C–type townships need to adopt land planning to control reductions in their settlements on the one hand, and on the other hand, they need to guide the return and increase in the population through industrial planning and economic policies to promote the development of the agricultural industry and its transformation into other industries.

5. Conclusions

This research measured and categorized the coupling of population and degree of settlement change of 1465 townships into four coupling types, and measured the urban attractiveness of the built–up areas of 12 prefectural–level cities in China's Heilongjiang Province; a model of urban–rural development forces was then constructed based on the two. Through the measurement of this model and the analysis of the urban–rural development relationship model, a new urban–rural development pattern was described that may be formed in the study area in the future. This pattern is conducive to achieving the integrated development of urban and rural areas in the region, as well as providing a basis for the scientific adjustment of regional land use policies in the future. The study obtained the following main conclusions:

Firstly, it was found that during the study period, the rural populations and settlements in the study area undergo significant spatial dynamic change, and the two have obvious coupling; the size of the coupling can promote the dynamic development trends of different types of villages. The townships in the study area were divided into four types of coupling: A–type (658) has generally high coupling values, and is the area most likely to produce new cities or satellite towns in the future; B–type (47) has the highest proportion of high coupling values of all types, and its future development trend is to die out faster; C–type (100) has a more even distribution of coupling values—the possibility of increasing hollowing out in the future is not high, and the possibility of turning to other types is not high; D–type (447) townships have generally low coupling values, and it is more difficult to continue to increase the intensity of settlements use, but they can be developed into regional center townships.

Secondly, this study found that under the maximum urban–rural development force, each township is "paired" with a city, forming a spatial cluster of bundles of radial lines centered on a particular city. Different types of rural coupled development types and their corresponding paired cities form different types of spatial linkage patterns of bundled radial clusters. The average values of the maximum attractiveness of different types of townships to the 12 prefecture–level cities indicate that the groups of urban–rural development relationships that generate the main interactions are not the same in each type. These main urban–rural development relationship clusters, together with the townships' own coupled interaction agglomeration characteristics, constitute the new urban–rural development pattern in the future.

Thirdly, the new urban–rural development pattern is a combination of many elements, including natural ecology and socio–economics; this is in line with the objective laws of development and is scientific in nature. Combined with the theory of echo and diffusion effects, it enhances the diffusion effect of rural areas with development advantages (A–type and D–type) and reduces the echo effect of rural areas with development disadvantages (B–type and C–type), thereby promoting integrated urban–rural development and realizing economic development in the region. At the same time, the pattern can guide future changes in land planning policies by optimizing the urban–rural development relationship and more rationally allocating township land resources, including various effects such as improving the efficiency of settlement use and protecting arable land.

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